Tagus Estuary hydro-biogeochemical model: Inter-annual validation and operational model update

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Abstract: The validation of the Tagus estuary hydro-biogeochemical model was performed for the period between 2006 and 2012 taking into account data of tide gauges, Acoustic Doppler Current Profiler (ADCP), in-situ water samples and multiparametric probes installed in two buoys located in different estuarine areas. This validation allowed to: verify the model results along several years with different hydrological regimes; overcome model limitations and improve the model configuration in order to represent the observed patterns in the Tagus estuary. As an outcome of this work, the Tagus estuary model implemented by the MARETEC research team was updated with a more refined resolution (200 m) for the entire estuary. The Tagus Estuary model was used in management studies for the wastewater treatment companies SIMTEJO and SIMARSUL and is currently running in operational mode.

Key words: operational modelling, validation, hydrodynamics, water quality, Tagus estuary

1. INTRODUCTION

The validation and implementation of a new hydro-biogeochemical operational model for the Tagus estuary (Portugal) with a high resolution is described in this paper. The model was implemented using a downscaling approach, which allowed defining ocean boundary conditions from a large-scale model. A vertically integrated (2DH) version of the Tagus Estuary model was firstly verified against data measured in the years 2006-2012. The 2DH model was useful to understand the Tagus estuary patterns, and it was also used in management studies for the wastewater companies SIMTEJO and SIMARSUL, helping to assess the impact of individual nutrient sources to the estuary biogeochemical cycle.

Although the 2DH model was useful for running long periods with a reasonable computational time, it is a simplification of the reality that has some limitations when simulating estuarine systems, mainly during periods of strong water column stratification observed in high river flow conditions and neap tides. Thus, a three-dimensional (3D) version of the Tagus Estuary model was developed in 2013, continuing the previously work. The 3D version is running in operational mode and providing online daily forecast results of hydrodynamics and water quality for the Tagus estuary. The model was developed by the MARETEC research team, using the MOHID water modelling system. The operational model will provide forecasting data to a web portal about the Tagus estuary, as a product of the ENVITEJO project.

2. MODEL SETUP

The hydrodynamic module is the core of the MOHID water modelling system. This is a three-dimensional hydrodynamic model that solves the Navier-Stokes equations, considering the Boussinesq and hydrostatic approximations. The equations are numerically solved using the finite volumes approximation concept with a generic vertical discretization, which allows simultaneous implementation of various types of vertical coordinates.

The vertical discretization of the Tagus Estuary model consists of 14 Cartesian layers overlapped by 7 Sigma layers. The vertical resolution is about 1 m near the water surface. The horizontal resolution is constant, with 351 x 405 cells of 200 m x 200 m. The model bathymetry was generated from the last update of the Portuguese Hydrographic Institute database for the Tagus estuary (Fig. 1).

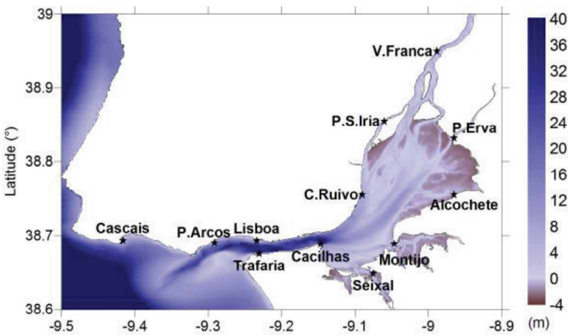

Fig. 1. Bathymetry (m) of the Tagus estuary relative to the hydrographic zero (2.08 meters below the mean sea level in Cascais) and locations of the tide gauges used to verify the model

results.Negative depths represent the intertidal zones that can be above water in low tides.

2.1. Boundary Conditions

The open boundary conditions for hydrodynamics and water properties are provided by the Tagus Mouth operational model, described by Campuzano et al. (2012). The Tagus Mouth model was implemented by the MARETEC research team mainly for the study of the estuary mouth and covers a larger area with a lower resolution (ranging from 2 km to 300 m). This model is also a downscaling of the Portuguese Coast Operational Model System (PCOMS), described by Pinto et al. (2012). PCOMS is forced by the FES 2004 (Finite Element Solution) tide model (Lyard et al., 2006). The tide is propagated from PCOMS to the Tagus Estuary model with the Flather (1976) radiation scheme, which enables to radiate external gravitational waves over the perturbation produced by other mechanisms, as the wind and the Coriolis force.

The atmospheric boundary conditions are provided by the WRF model (Weather Research and Forecasting), implemented by the Instituto Superior Técnico Meteorological team with a 3 km resolution covering the Tagus estuary area (Trancoso, 2012). The Tagus river flow is defined in the operational model by the latest data available from the Almourol hydrometric station (http://snirh.apambiente.pt). The freshwater input of the other two most important rivers, Sorraia and Trancão, were defined by monthly average values. Water properties concentrations for all rivers inputs, as well as the discharges of 21 wastewater plants to the estuary, come from climatological analysis.

2.2. Automatic Running Tool

The Automatic Running Tool (ART) developed at MARETEC allows running the Tagus Estuary model in operational mode. This software has been designed to enable automatic simulations and can be used to run past periods or in nowcast/forecast mode. ART is responsible for:

a) preparation and configuration of model inputs, including downloading, extraction, glueing and interpolation of boundary and initial conditions;

b) running model simulations;

c) backup and storage of output results;

d) generation of maps and time series based on model results;

e) sending emails to control the operational system.

3. VALIDATION

The most complete study about tidal propagation inside the Tagus estuary was carried out by the Portuguese Hydrographic Institute (Lemos, 1972), based on water level measurements in sixteen stations over a period of several months. The tide propagation into the Tagus Estuary model was assessed by comparing the harmonic constituents extracted by harmonic analysis of the water level results and tide gauges data from Lemos (1972), making use of the MATLAB T_Tide package (Pawlowicz et al., 2002). Furthermore, the velocity results were compared with six month data from an Acoustic Doppler Current Profiler (ADCP) installed in a buoy located in the Tagus estuary (Fig. 2).

The companies SIMTEJO and SIMARSUL have been monitoring the water quality in the Tagus estuary in nineteen stations since 2004 with a trimestral frequency. The monitoring data were used to verify the model results of: temperature, salinity, cohesive suspended solids, dissolved oxygen, ammonia, nitrate, total phosphorous and chlorophyll. In July of 2012, two multiparametric probes were installed in different estuarine zones, providing measured data every twenty minutes. These data made possible to assess the fortnightly and daily variation in the measured parameters (temperature, salinity, pH, dissolved oxygen, turbidity and chlorophyll). The location of the monitoring stations and the multiparametric probes is presented in Fig. 2.

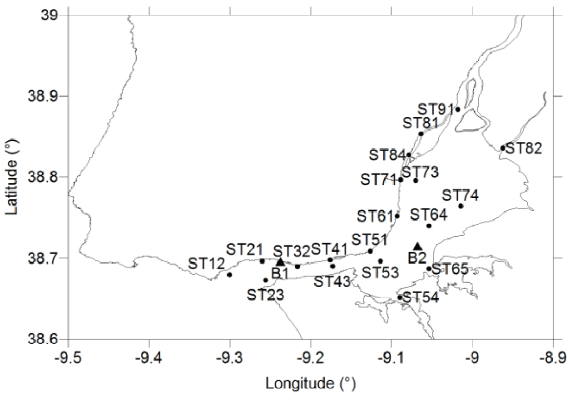

Fig. 2. Location of the monitoring stations (•) and buoys (▲) where are installed the multiparametric probes. The ADCP is located in the buoy B2.

4. RESULTS AND DISCUSSION

The amplitudes and phases of the main tidal component in the Tagus estuary (M2), for the tide gauges showed in Fig. 1, are presented in Fig. 3. The tide amplitude is amplified throughout the estuary until the upper area, where it decreases due to bottom friction. The results of amplitude and phase are in general very accurate. The largest errors occurred in V. Franca station, with -0.22 m of amplitude and 12.7° of phase. The grid resolution of 200 m is not sufficient to represent the small channels geometry in the upper area of the estuary, which is possibly the reason for these larger differences.

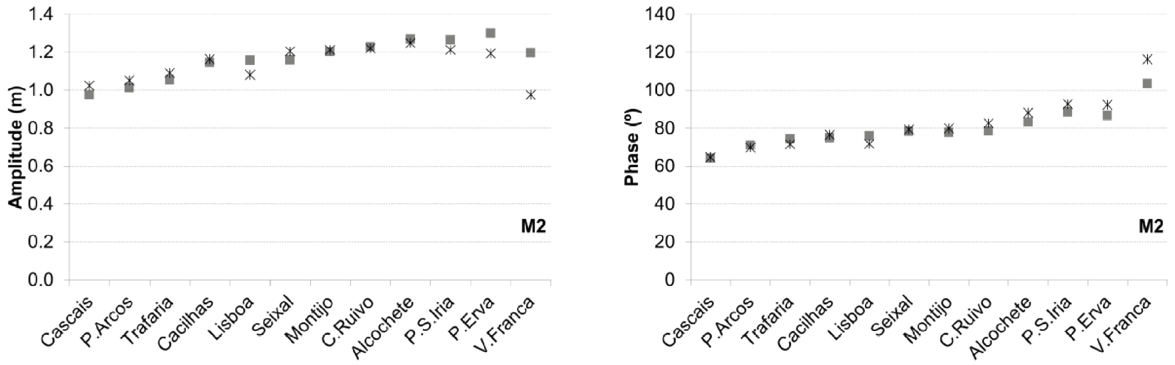

Fig. 3. Amplitudes(on left) and phases(on right) extracted by harmonic analysis of the data from Lemos (1972) ( ) and the model results ( ) for the most important component (M2) in the Tagus estuary.

The velocity results showed a good correlation with the ADCP measured data (Fig. 4). The Root Mean Square Error (RMSE) was 0.20 for the six month time series measured in 2012. The velocity intensities have a large oscillation caused by the tidal cycle. The higher velocity intensities occur in the ebb tides when the water level decreases, with peak values in the order of 1.0 m/s in the spring tide in this location.

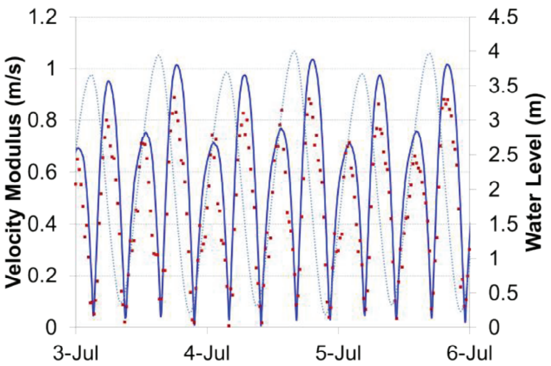

Fig. 4. Comparison between the velocity modulus results (–) and data (▪) measured by the ADCP installed in the buoy B2 for July of 2012. The water level (…) is plotted to show the effect of tide on velocity.

In order to validate the water properties model results in the simulated years (2006-2012), we used the concentrations measured in the monitoring stations, as well as statistical values (maximum, median and minimum) calculated using monthly data series. The statistical analysis gives a more representative indication of concentrations variability along the year in different estuarine zones. In general, the model successfully represented the observed data. The suspended sediment results are compared against data measured in some monitoring stations along the Tagus estuary in Fig. 5. Concentrations during spring tides often exceeds 50 mg L^{-1} in stations located in the upper shallow estuary (ST84, ST64), while in the deeper areas near the estuary mouth concentrations were normally less than 50 mg L^{-1} (ST12).

The data from the two multiparametric probes were used to assess the fortnightly and daily variation of temperature, salinity, dissolved oxygen, and chlorophyll. Furthermore, turbidity data were used to verify the variation in the suspended sediment results. The chlorophyll results were compared with data from the two multiparametric probes (Fig. 6). It is possible to observe the oscillation in chlorophyll concentrations due to the fortnightly tidal cycle, mainly in the location of buoy B2. The estuary turbidity increases in spring tides, when the water velocities are higher, enabling the erosion of a larger amount of deposited sediments. The light availability is considered the main limitation factor to the phytoplankton growth in the Tagus estuary, which was confirmed by the model results.

The probes data also allowed verifying differences in the chlorophyll concentrations during ebb and flood tides. The concentrations increase during ebb tides, because the water from the shallowest and most productive estuarine zones passes through the buoys location. On the other hand, during flood tides the water comes from the deepest and least productive zones.

5. CONCLUSION

The model validation performed along several years allowed: to verify the model results in different hydrological regimes; access the model limitations and improve the model configuration in order to represent the observed Tagus estuary patterns. The model results were validated with harmonic analyses of tide gauges data and measured velocities, demonstrating a reliable representation of the estuary hydrodynamics. The water properties data measured in the monitoring stations located in different estuarine zones allowed a spatially verification of the model results. On the other hand, the data of the multiparametric probes allowed a verification of the fortnightly and daily variation in the water properties. The Tagus Estuary operational model permitted to integrate the data measured in different locations and time scales, providing a better understanding of the Tagus estuary dynamics and forecasting results for different type of users.

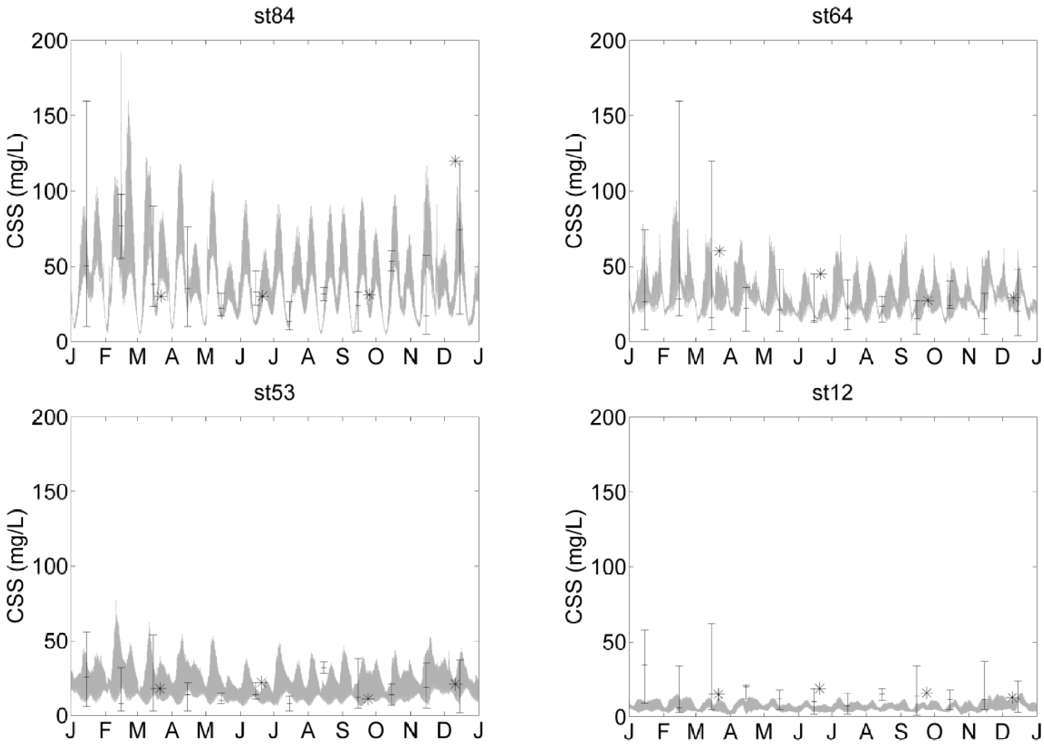

Fig. 5. Comparison of simulated (–) cohesive suspended sediment (CSS) concentrations and measured data in the year 2012 (*) and the maximum, median and minimum of the monthly data series between 2004 and 2012 (I)

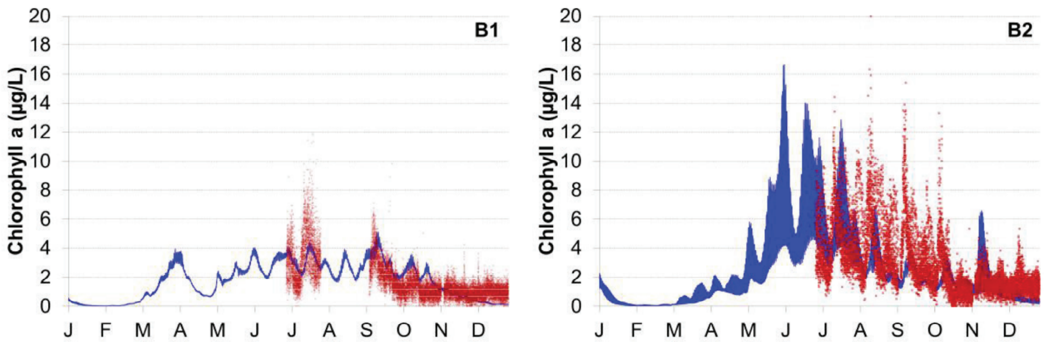

Fig. 6. Chlorophyll concentration results (–) compared against measured data (▪) in the two multiparametric probes located in buoys B1 and B2

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